ACID MINE DRAINAGE ABATEMENT IN THE LOWER ROCK CREEK WATERSHED – McCREARY COUNTY, KENTUCKY

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ABSTRACT

Rock Creek above White Oak Junction is a beautiful boulder strewn stream designated as a Kentucky Wild River and is the premier mountain trout stream in Kentucky. Below White Oak Junction acid mine drainage (AMD) from over 40 coal mine portals and eight pyrite-rich refuse dumps has decimated aquatic life and rendered the stream virtually lifeless. The Rock Creek Task Force, a group of 12 state and federal agencies and conservation organizations, was formed to find solutions to the degraded water quality in the lower Rock Creek Watershed. Funding was provided by several of the Task Force partners including an EPA 319 Clean Water Action Plan grant, an Appalachian Clean Streams Initiative grant, a PRIDE grant from NOAA, KYAML's annual grant, and a USGS cost share agreement.

In 1998 a biological and water-monitoring program began in the lower Rock Creek watershed. Acid loading was calculated and in spring of 2000 dosing of selected tributaries with sand-sized limestone particles began. Within two months the flow out of Rock Creek into the Big South Fork of the Cumberland River changed from net acidic to net alkaline. After four months similar results were obtained in White Oak Creek, a major source of AMD to Rock Creek.

In the fall of 2000 construction began on a reclamation project targeting several of the worst AMD sites in the lower Rock Creek watershed. Pyrite-rich refuse was removed from the banks of Rock Creek. Open limestone channels were installed routing AMD through the limestone before discharging into the stream, and a modified vertical flow wetland was installed at a site with limited distance between the AMD source and the receiving stream. Dosing with limestone sand continued monthly with permanent dosing stations being established farther upstream in the impacted tributaries.

Water monitoring results continue to be encouraging with reductions in acidity and dissolved metals in the affected streams. Fish sampling has revealed that fish populations are already being re-established in once lifeless sections of White Oak Creek and lower Rock Creek. Macro-invertebrate sampling indicates that species diversity and numbers are also improving.

INTRODUCTION

Study Area Description

Rock Creek originates in Pickett State Park, Tennessee, traverses 21 miles in McCreary County, Kentucky and empties into the Big South Fork of the Cumberland River within the Big South Fork National River and Recreation Area, which is administered by the National Park Service. Rock Creek lies mostly within lands managed by the U.S. Department of Agriculture Forest Service (Fig. 1). Rock Creek is a beautiful boulder strewn stream designated as a

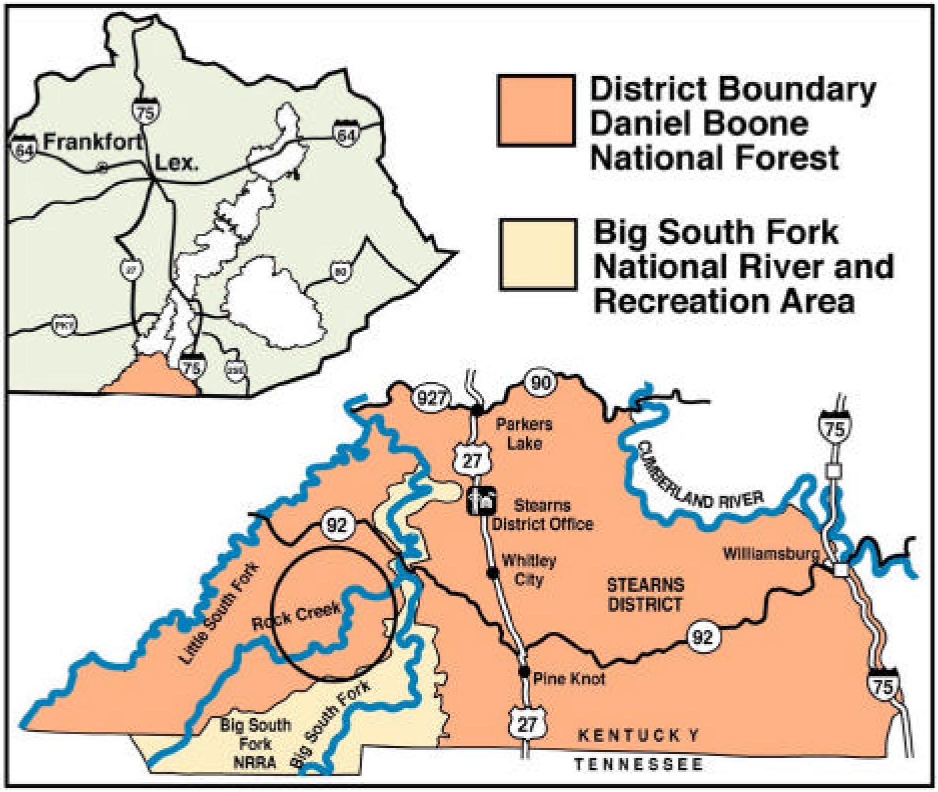

Figure 1. Study area (USFS, 2002).

Kentucky Wild River from the Kentucky State line to White Oak Junction. Rock Creek above White Oak Junction is the premier mountain trout stream in Kentucky. Below White Oak Junction acid mine drainage (AMD) from over 40 coal mine portals and eight pyrite-rich refuse dumps has decimated aquatic life and rendered the stream virtually lifeless (Fig. 2). The impacted area of the Rock Creek watershed includes White Oak Creek from Cabin Branch downstream to the confluence with Rock Creek at White Oak Junction, as well as Rock Creek from White Oak Junction to the confluence with the Big South Fork. All tributaries to White Oak Creek and this portion of Rock Creek are included. The project is located within the impacted area specifically in Cabin Branch, Cooperative North Portal, and Jones Branch of White Oak Creek, and in Roberts Hollow, Paint Cliff, Poplar Spring Hollow, Koger Fork, and the mouth of Water Tank Hollow on Rock Creek.

Land-use Activities

Underground coal mining began in the project area in the first decade of the 20th century and continued through the 1960's. Several small towns were built supporting the mining and lumber industries of the area. Several of the towns including Yamacraw, Fidelity, and Co-Operative no longer exist. With the exception of the railroad right of way, owned by the K & T Railroad Company, and a few small private in-holdings, the project area is managed by the United States Forest Service. Rock Creek is a major recreational attraction and is visited by thousands yearly. Fishing, hunting, hiking, backpacking, and camping are just a few of the interests pursued by visitors.

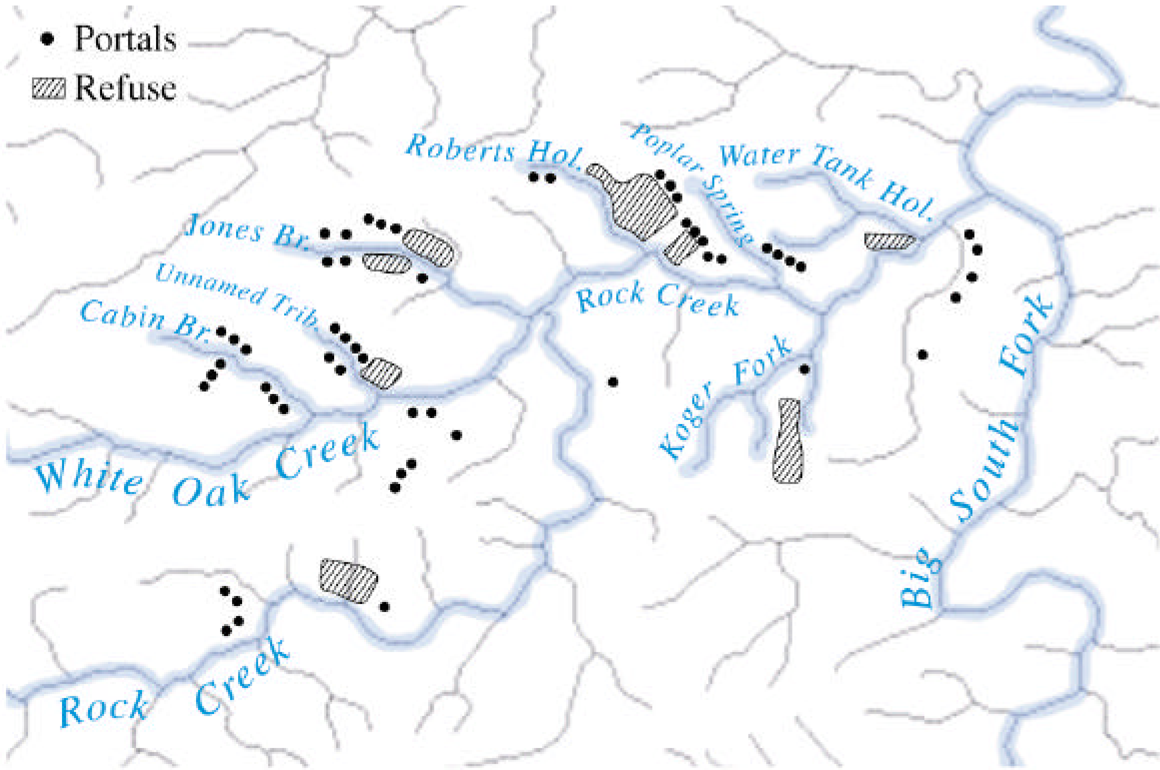

Figure 2. Lower Rock Creek Watershed portals and refuse fill locations.

Project Description

This project addresses several AMD sources in the Rock Creek watershed. The Rock Creek Task Force, a group of 12 state and federal agencies and conservation organizations, was formed to find solutions to the degraded water quality in the lower Rock Creek watershed. Members of the task force include: the Kentucky Division of Abandoned Mine Lands (AML), Kentucky Division of Water (DOW), federal Office of Surface Mining (OSM), Kentucky Department of Fish and Wildlife Resources (KDFWR), National Park Service (NPS), United States Forest Service (USFS), Trout Unlimited (TU), Kentucky Department for Surface Mining Reclamation and Enforcement (DSMRE), United States Geological Survey (USGS), United States Army Corps of Engineers (COE), United States Fish and Wildlife Service (USFWS), and the United States Natural Resources Conservation Service (NRCS). Funding was provided by several of the task force partners including an Environmental Protection Agency (EPA) 319 Clean Water Action Plan (CWAP) grant, an Appalachian Clean Streams Initiative (ACSI) grant, a Personal Responsibility In a Desirable Environment (PRIDE) grant from the National Oceanic and Atmospheric Administration (NOAA), KYAML's annual grant, and a USGS cost share agreement.

The overall plan was developed by the Kentucky Division of Abandoned Mine Lands with the partnership and assistance of the above agencies and organizations. The goal of the Rock Creek Project is to show a demonstrable reduction in sediment and acidity entering Rock Creek and to return the land where the coal processing refuse dumps are located to a vegetated state compatible with the surrounding land.

Construction activities to attain these goals included removal of the acid forming material from the banks of Rock Creek at the 3-acre Water Tank Hollow refuse site and at the Paint Cliff coal load out sites. The acid forming material was treated and placed in a compacted fill at the Roberts Hollow refuse site. Open limestone channels were constructed at the Cabin Branch site, the Co-op North site, the Roberts Hollow site, the Paint Cliff site, the Poplar Spring site, and the Water Tank Hollow site. A modified vertical flow system was constructed at the Paint Cliff site. Limestone sand application sites were developed on Cabin Branch, Jones Branch, Roberts Hollow, Poplar Spring Hollow, and Koger Fork.

METHODS

Data collection and methodology included a water monitoring program conducted by the United States Geological Survey (USGS) on a cost share basis with AML and a biological monitoring program conducted by AML, USFS and KDFWR personnel (Fig. 3). Soil and refuse analysis including computer modeling utilizing the Revised Universal Soil Loss Equation (RUSLE) was conducted by AML. Reclamation techniques were chosen after analysis of water chemistry, soil and refuse testing and site specific conditions.

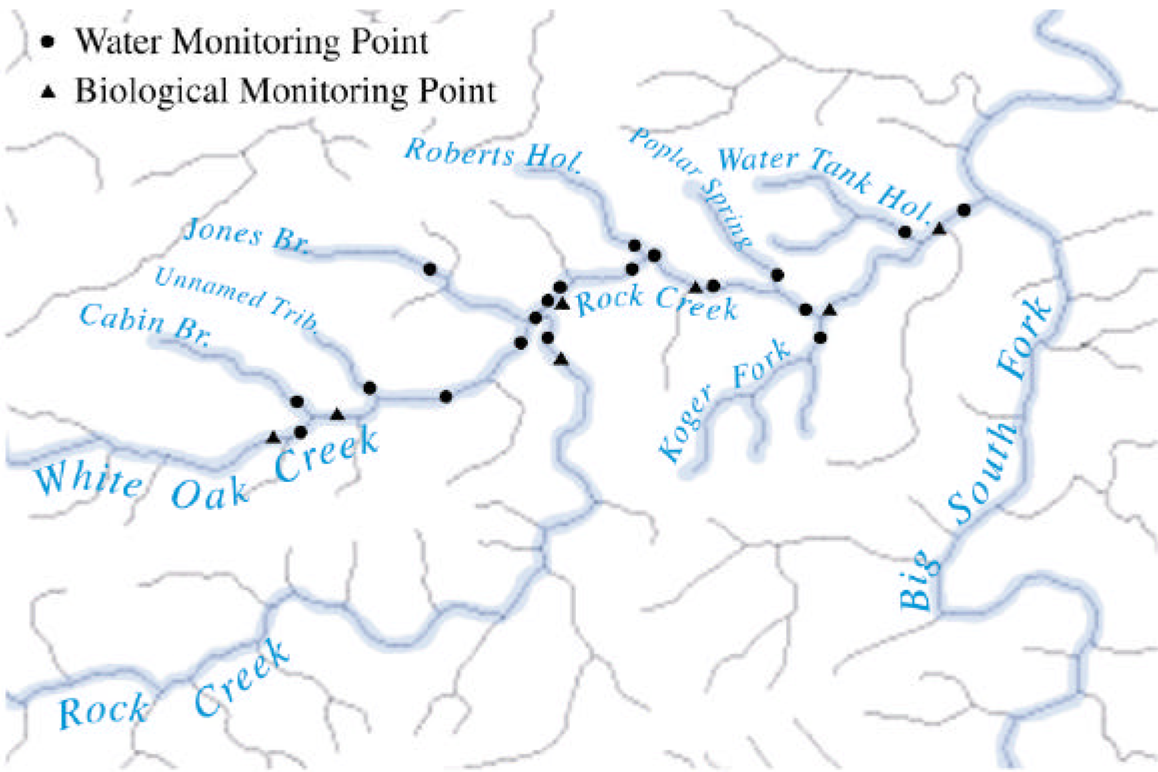

Figure 3. Water and biological monitoring sites in the lower Rock Creek watershed.

MONITORING

Water Monitoring

DSMRE personnel collected water quality data for 41 portals and seeps in the study area in the spring of 1995. The portals were sampled for pH, specific conductance, dissolved oxygen, and discharge in the field; alkalinity, acidity, total dissolved solids, total, dissolved, and ferrous iron, total and dissolved manganese, total aluminum, and sulfate were analyzed in the lab. Loading was calculated and passive treatment options were explored using the water chemistry for each portal discharge.

In the fall of 1998 a monitoring program was started monitoring the main stem of Rock Creek and the mouths of the main tributaries contributing acid mine drainage to the lower Rock Creek watershed. The parameters tested were the same as for the portals with the exception of dissolved oxygen and ferrous iron. Dissolved aluminum and total calcium were added as test parameters. The mouths of the tributaries and the main stem of Rock Creek were chosen as monitoring points to include all of the acid drainage sources and any natural buffering which may occur within the watershed. The sites were monitored monthly, for a period of eighteen months before construction activities began, to collect background data. The sites were monitored monthly during construction of the project and monthly thereafter to demonstrate project success.

All sample collection, preservation, and analysis were conducted in accordance with “Standard Methods for the Examination of Water and Wastewater” and/or “U.S. Geological Survey Protocol for the Collection and Processing of Surface-Water Samples for the Subsequent Determination of Inorganic Constituents in Filtered Water” – U.S. Geological Survey Open-File Report 94-539. Discharge was measured by current velocity meter or by the “bucket and stopwatch” method where possible. Conductivity and pH were measured using calibrated pH and conductivity meters.

Biological Monitoring

Aquatic macroinvertebrates were collected spring and fall by a series of three surber samples per station, along with one triangular kick-net sweep to cover all habitat types in the sample area. All whole samples were picked in the field, stored in 70% ethanol, and returned to the USFS Winchester office or AML Frankfort office for sorting and identification to the lowest possible taxon. After sorting and identification, the data was evaluated using the modified Hilsenhoff Biotic Index (HBI) (Lenat, 1993) to determine the overall pollution tolerance of the macroinvertebrate community and the degree to which the habitat is impaired. Other metrics used includes the Total Number of Individuals, Ephemeroptera/Plecoptera/Trichoptera Richness (EPT), and Percent Dominant Taxon.

Fish were collected in early summer by the use of a Smith-Root model 12A battery powered backpack electrofishing device. Fish collected were identified in the field when possible, with voucher specimens being returned to the lab for positive identification. Identification was to the lowest possible taxon. Type specimens were preserved in 10% buffered formalin for 1-2 weeks, then rinsed and transferred to 70% ethanol for long-term preservation and storage. After final identification the data was evaluated using the Index of Biotic Integrity (IBI) to determine the overall structure and health of the piscid community as an indicator of aquatic habitat health. Also, Catch Per Unit of Effort (CPUE) of shocking time was considered as a measure of relative abundance.

Biological monitoring stations were used for both fish and macroinvertebrate sampling. Site selection criteria included ease of repositioning, and the ability to determine the effects of AMD treatments within the project area on the main stem of Rock Creek. All sites except for the control sites RC-00 and WC-01 are downstream from the AMD impacted tributaries.

Macroinvertebrate samples were collected, processed, and the resulting data analyzed by USFS personnel. Fish samples were collected, processed, and analyzed by KDFWR personnel. Biologists from DOW and AML assisted in collection, processing, and identification of both macroinvertebrates and fish.

Soil and Refuse Analysis

The Revised Universal Soil Loss Equation (RUSLE) was used to calculate soil loss from the project area before, and after, reclamation was completed. This provided a means of estimating the reduction in sediment entering Rock Creek from the Water Tank Hollow site after completion of the project. The annual acid load reduction into Rock Creek from the Water Tank Hollow refuse site was calculated using the acidity data from the refuse analysis in combination with the reduction in quantity of refuse washing into Rock Creek annually from the Water Tank Hollow refuse site as calculated by RUSLE.

The coal processing refuse was sampled at various locations in the project area. Any areas that had noticeably different soil properties were sampled and analyzed as separate samples. The soil/refuse samples were analyzed for soil water pH, buffer pH, available phosphorus, available potassium, and potential acidity.

ACID MINE DRAINAGE ABATEMENT TECHNOLOGIES INSTALLED

Limestone Sand Treatment

During testing of a self-feeding rotary drum stream neutralization system that ground limestone aggregate into a slurry, Zurbuch (1989) found that undissolved sand-sized limestone particles continued to be reactive in stream sediments and significantly reduced acidity. Further research into the use of limestone fines as a method to treat streams acidified by acid deposition corroborated Zurbuch's rotary drum results (Ivahnenko et al., 1988).

Sand-sized limestone may be directly dumped into acid mine drainage impacted streams at various locations in watersheds. The limestone sand is picked up by the stream flow and redistributed downstream, neutralizing the acid as the stream moves the limestone as bed load. The limestone sand in the streambed reacts with acid in the stream, causing neutralization. Coating of limestone sand particles with iron oxides can occur, but the agitation and scouring of the limestone in the streambed keep fresh surfaces available for reaction.

Water monitoring was conducted to determine the acid load being contributed by each tributary to the lower Rock Creek watershed. In the spring of 2000 a pilot project was started dosing the lower Rock Creek watershed monthly with limestone sand. The purpose of the pilot project was to determine the stream response to dosing at the calculated rates. Existing culvert outlets from the main tributaries into White Oak Creek and Rock Creek were used as dosing sites. If the pilot project proved successful permanent-dosing stations would be constructed in the main tributaries.

Direct application of limestone sand to treat acidified streams is the least expensive method of treatment available based on the cost per ton of acid neutralized (Zurbuch, 1996; Zurbuch et al., 1996). Limestone sand dosing does not require the large capital investment or the operation and maintenance costs of mechanical stream dosing systems.

The annual cost to treat the acid load in the lower Rock Creek watershed with limestone sand after construction of all application sites and after the first year of dosing when rates are doubled was calculated to be $15,000. The Division of Abandoned Mine Lands, as part of its annual grants from the Office of Surface Mining, budgets for the continued dosing of the lower Rock Creek watershed with limestone sand into the foreseeable future. It is anticipated that at some time in the future the United States Forest Service will assume the responsibility for dosing the lower Rock Creek watershed. If and when this occurs AML will relinquish responsibility for the dosing to the USFS.

Refuse Removal and Treatment

The Rock Creek Clean Water Action Plan Project involved the removal of 25,000 cubic yards of highly acidic coal mine refuse from the banks of Rock Creek near Water Tank Hollow and from the Paint Cliff coal load out site. The refuse was a significant source of sedimentation and acid mine drainage (AMD) into Rock Creek, as well as a visual blight to the surrounding forested area. The refuse was loaded and hauled to an existing refuse area in Roberts Hollow. The refuse was placed in six-inch to eight-inch lifts near the toe of the existing refuse fill. Foundation benches were excavated and an agricultural limestone barrier was placed prior to placement of the refuse. Agricultural limestone was incorporated into each lift. The rate of 20 tons of agricultural limestone per 100 cubic yards of refuse was used. The rate of limestone mixed with the refuse was determined by soil tests. Suitable borrow material for soil cover on the refuse was found in the fill area and was placed two feet thick on top of the final lift of refuse. The area filled had sparse vegetation and revegetation efforts following placement of the fill has improved the vegetative cover on the site, reducing the sediment load to the stream. The refuse fill area was seeded with a mix of acid tolerant warm and cool season grasses and legumes.

Open Limestone Channels

Open limestone channels (OLCs) were installed at the Cabin Branch portal discharge site, Co-op North portal discharge site, Roberts Hollow refuse fill site, Paint Cliff portal and refuse fill sites, Poplar Spring Hollow portal site, and the Water Tank Hollow refuse removal site. A limestone channel 500 feet in length was constructed at the Cabin Branch portal discharge. The portal discharge was diverted into the OLC before flowing into Cabin Branch. At the Co-op North portal the mine drainage was diverted into a 500 foot long OLC before discharging into White Oak Creek. A limestone channel 1000 feet in length was constructed immediately above the refuse fill area at the Roberts Hollow site. A limestone channel 800 feet in length was installed in the natural drain on the southeast side of the Roberts Hollow fill area. The limestone channels in Roberts Hollow intercept acidic water from the upper slopes of the refuse fill area, diverting acidic water away from the new fill, and provide treatment to the water before discharging into the main tributary and Rock Creek. An OLC 130 feet in length was installed at the mouth of Poplar Spring Hollow. At the Paint Cliff site an OLC was installed to intercept and carry water from the toe of the refuse fill and from a deep mine discharge to a sediment basin before entering a vertical flow system. Acid seeps were intercepted by another OLC before discharging into Rock Creek.

At the Water Tank Hollow site a natural drainage feature was encountered during excavation of the coal mine refuse from the banks of Rock Creek. An open limestone channel was installed in the steep natural drain encountered during excavation of the refuse. Acid seeps were encountered near the toe of the slope after removal of the refuse from the Water Tank Hollow site. An open limestone channel was installed along the toe of the slope picking up the acid water and directing it through the limestone before discharging into Rock Creek.

The open limestone channels were lined with a few inches of limestone sand before placement of the crushed limestone. The crushed limestone was four to nine inches in size except for high flow areas. In high flow areas the crushed limestone was nine to eighteen inches in size.

Diverting AMD into open channels or ditches lined with limestone rock increases alkalinity in the acid water through limestone dissolution (Ziemkiewicz et al., 1994). Past assumptions have held that limestone coated with iron and/or aluminum hydroxides (armored limestone) ceased to dissolve, but experiments show that coated limestone continues to dissolve at reduced rates, as low as 20% of the rate of unarmored limestone (Pearson and McDonnell 1975). Studies have demonstrated that the rate of dissolution for armored limestone in the field may be higher than found in previous laboratory studies (Ziemkiewicz et al., 1997). Field experiments show considerable reductions in acidity by treatment with OLCs (Ziemkiewicz et al., 1994). Another problem is that precipitates tend to settle into and plug the voids in limestone beds forcing water to move over rather than through the limestone. While both armoring and plugging are caused by the precipitation of metal hydroxides, they are two different problems. Maintaining a high flushing rate through the limestone bed can minimize plugging of voids. Armoring, however, occurs regardless of the water velocity. Channel gradient and channel lengths are design factors that can be varied for optimum performance. Optimum performance is attained on slopes exceeding 20%, where precipitates are washed from limestone surfaces and kept in suspension by high flow velocities (Skousen et al. 1998). Dissolved metals sorb onto the surfaces of the precipitates in suspension, further reducing the amount of dissolved metals in the water. By adjusting the length of OLCs to account for reduced dissolution rates from armoring, and maintaining steep gradients, open limestone channels may be designed and constructed for long term treatment of AMD. Diverting AMD through OLCs before and/or after treatment with other passive systems can maximize treatment and metal removal.

Vertical Flow Systems

Vertical flow systems were conceived as a way to overcome the alkalinity generation limitations of an anoxic limestone drain and the large area requirements for compost wetlands. The vertical flow system consists of a treatment cell with a limestone under-drain topped with an organic substrate and standing water. The water flows vertically through the organic substrate that strips the oxygen from the water, making it anoxic. The water then passes through the limestone, which dissolves, increasing alkalinity. The water is discharged through a pipe with an air trap to prevent oxygen from entering the treatment cell. Highly acidic water can be treated by passing the water through a series of treatment cells. A settling pond and an aerobic wetland where metals are oxidized and precipitated typically follow the treatment cells.

Problems associated with vertical flow systems include plugging of the pipes with aluminum precipitate, which must be periodically flushed when aluminum loading is high, and precipitation of metals in the organic substrate which may clog, preventing flow into the limestone under-drain.

A modified vertical flow system eliminating the use of pipes in the bottom of the treatment cell and eliminating the standpipe to control water levels and exclude atmospheric oxygen was installed at the Paint Cliff site (Fig. 4). The treatment cell was designed to be self-flushing. This site has high aluminum concentrations, ranging from 12 mg/l to 83 mg/l pre-construction. Iron concentrations are also high, ranging from 20 mg/l to 274 mg/l pre-construction. The modified design includes a treatment cell followed by a second cell (Fig. 5). A smooth wall 36-inch pipe installed at the bottom of the treatment cell connects the treatment cell to the second cell. Because of the direct connection between the treatment cell and the second cell via the 36-inch pipe, the spillway of the second cell controls the water level of the treatment cell. The positive slope on the treatment cell and the 36-inch outlet pipe towards the second cell encourages flow of aluminum precipitates from the treatment cell into the second cell. The second cell is excavated deeper than the bottom of the 36-inch pipe to provide storage for any precipitates flushed into it. With adequate freeboard in the treatment cell, as precipitate begins to clog the limestone bed, the water level rises in the treatment cell increasing head and flushing the precipitate into the second cell. The elimination of small diameter pipes and the flow-through design of the treatment cell should minimize clogging with precipitates.

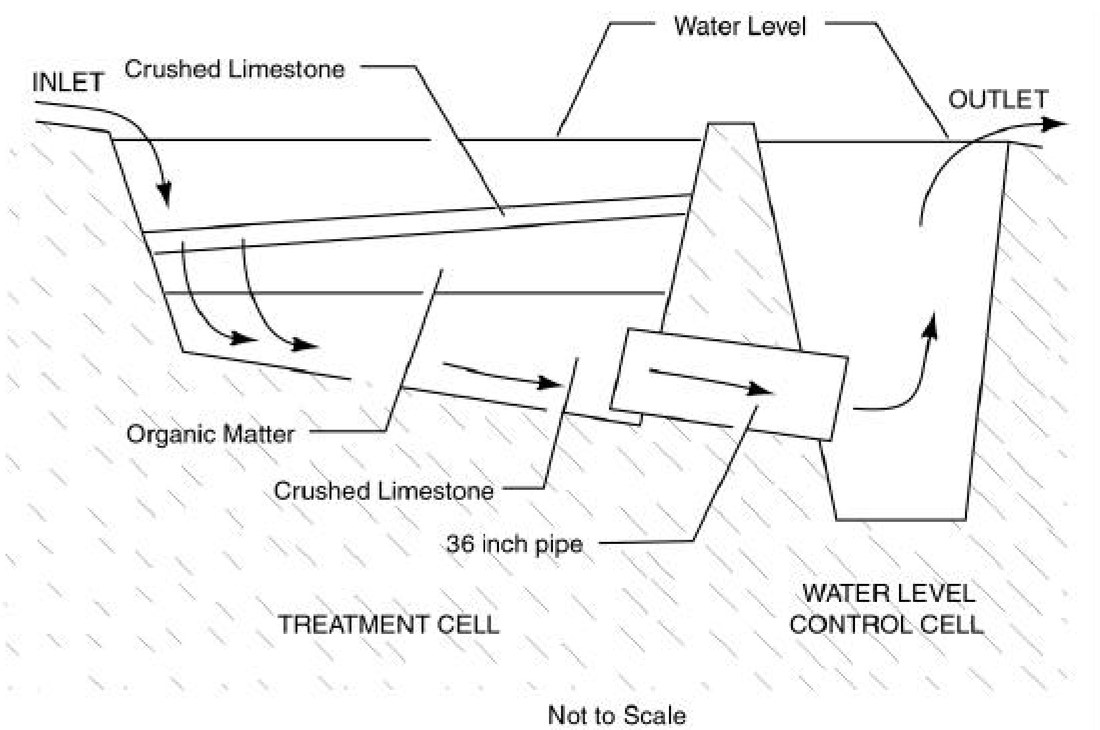

Figure 4. Modified Vertical Flow System detail.

Figure 5. Paint Cliff Vertical Flow System components.

RESULTS

Limestone Sand Dosing

In the spring of 2000 a pilot project began, dosing White Oak Creek and Rock Creek monthly with limestone sand at the mouths of each tributary that were a significant source of AMD. The rate was determined by acid loading calculations. Limestone sand was added at double the calculated rate. The pilot project continued with monthly dosing until the fall of 2001 when it ended due to low flow conditions. After two months of dosing, water quality at the mouth of Rock Creek changed from net acidic to net alkaline (Fig. 6). After four months of dosing, water quality at the mouth of White Oak Creek changed from net acidic to net alkaline (Fig. 7). Based on the positive results of the pilot project the decision was made to build permanent dosing stations in the main tributaries and continue with monthly dosing. Monthly dosing resumed in late winter with the increase in base flow. The rate of dosing continued to be double the calculated rate for the first year, and was reduced to the calculated rate thereafter. Dosing at double the calculated rate for the first year results in accumulation of one-year's worth of neutralization potential in the streambed. After two months of dosing the net acid load from Rock Creek into the Big South Fork of the Cumberland River was reduced from a monthly average of 110 metric tons (121 US tons) per month before dosing to a monthly average of 0.063 metric tons (0.069 US tons) per month (Fig. 8). After four months of dosing the net acid load entering Rock Creek from White Oak Creek, for the months having flow, was reduced from an average of 13 metric tons (14 US tons) per month before dosing to an average of 0.015 metric tons (0.017 US tons) per month (Fig. 9).

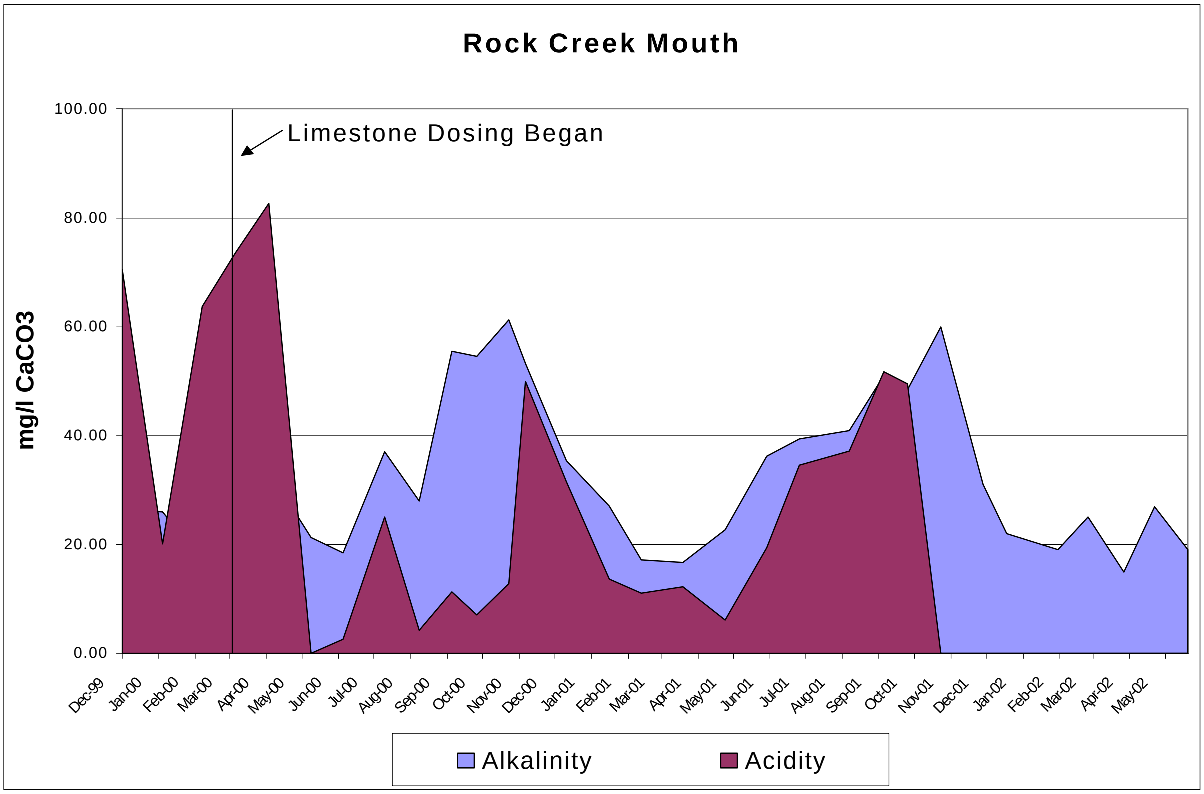

Figure 6. Rock Creek Acidity and Alkalinity

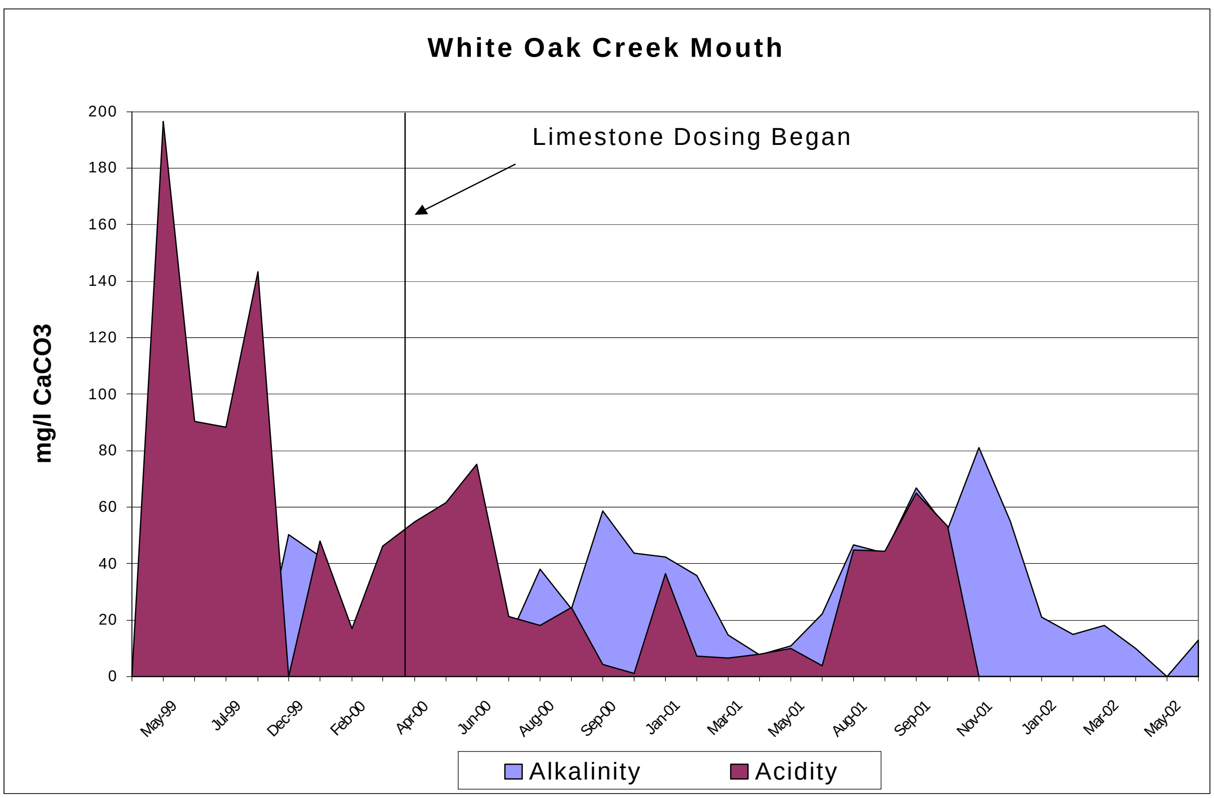

Figure 7. White Oak Creek Acidity and Alkalinity

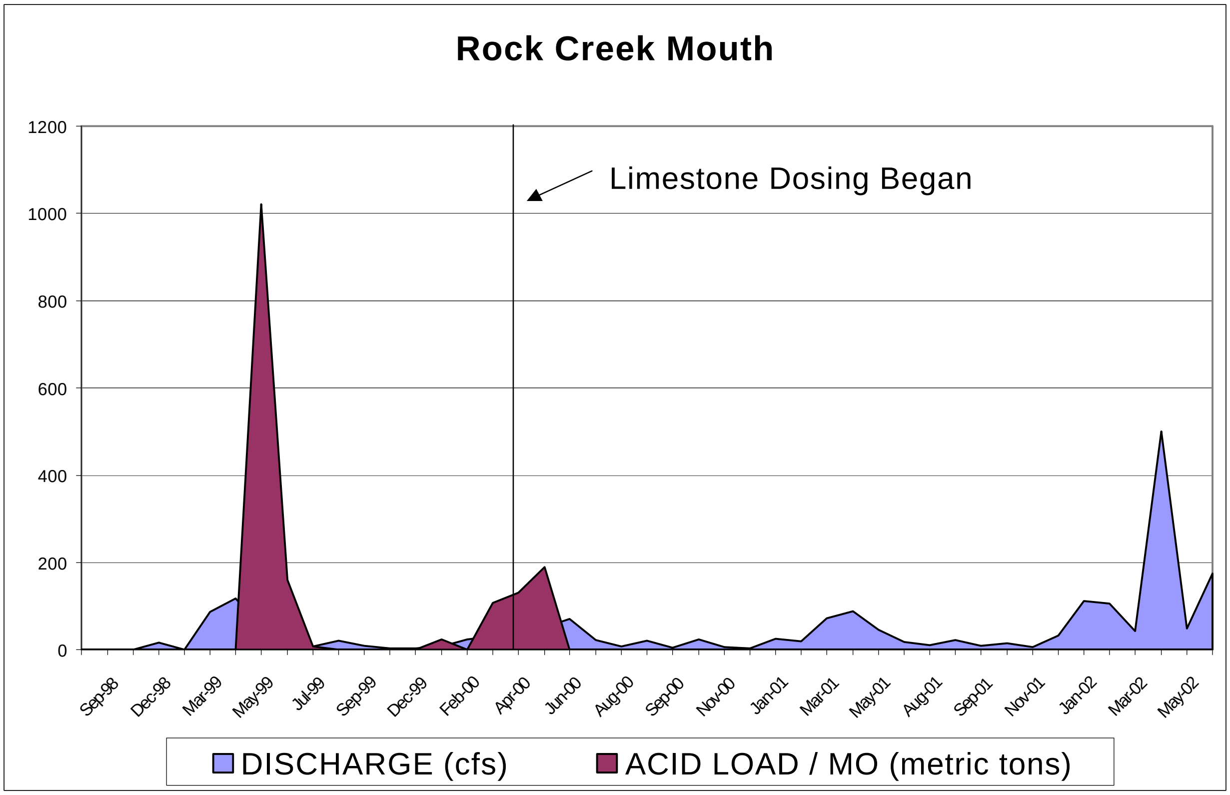

Figure 8. Rock Creek acid load

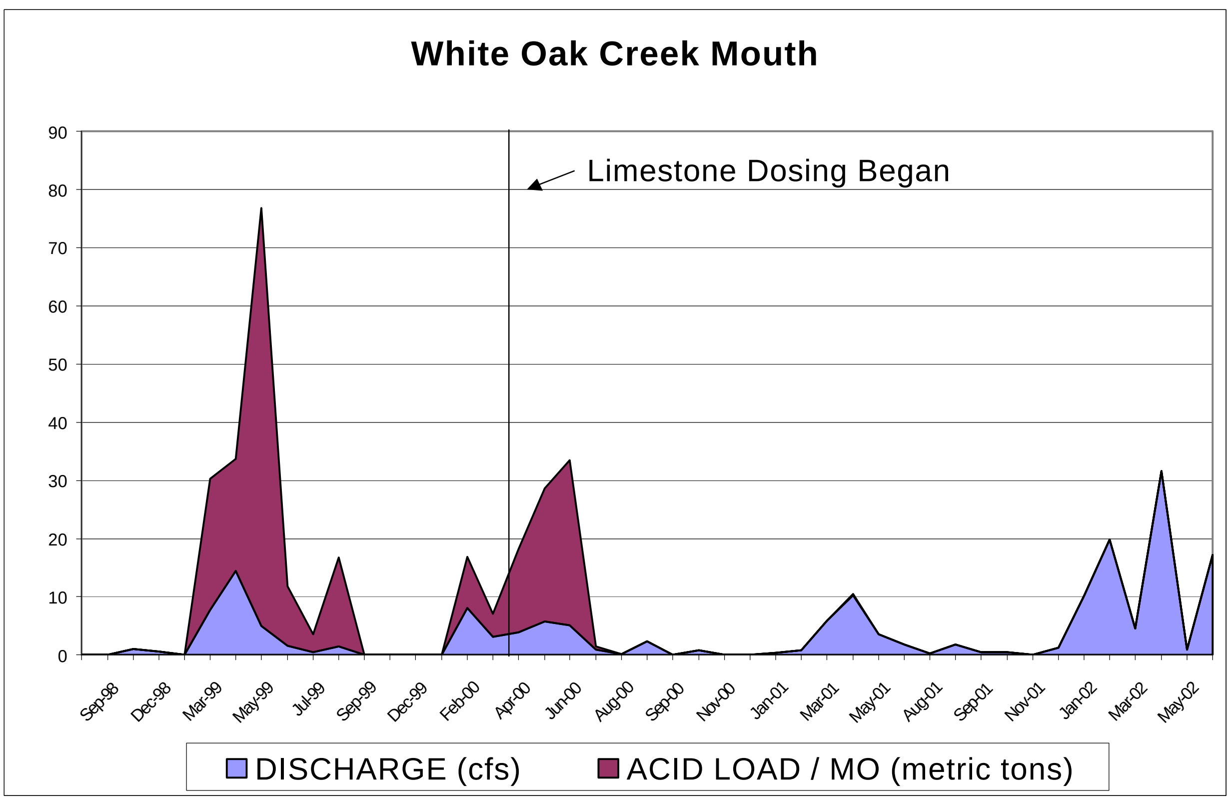

Figure 9. White Oak Creek acid load

Refuse Removal and Treatment

The Water Tank Hollow site was a 3-acre coal processing refuse disposal site on the north bank of Rock Creek (Fig. 10). This project involved the removal of 20,000 cubic yards of highly acidic coal mine refuse from the Water Tank Hollow site and the removal of 5,000 cubic yards of refuse from the Paint Cliff site. The refuse was hauled to an existing sparsely vegetated fill area in Roberts Hollow, treated with agricultural limestone at rates determined by soil testing, and placed in compacted lifts (Fig. 11). The computer programs SEDCAD4 and RUSLE were used to calculate the soil/refuse loss from the Water Tank Hollow refuse site each year. It was calculated that the annual soil/refuse loss was about 500 tons per year. The refuse was sampled and found to have a potential acidity of 165 tons $CaCO_3$ per kiloton of refuse. Removal of the refuse from the Water Tank Hollow site resulted in a reduction of 82.5 tons of acidity per year from the direct washing of the refuse into the stream. The actual acid load reduction is higher due to the formation of sulfur salts in the refuse and subsequent dissolution and runoff of acid into the stream during precipitation events. It was not possible to directly monitor the acid runoff at this site due to the nonpoint source nature of the three acres of acidic refuse located on the north bank of Rock Creek.

After removal of the refuse from the Water Tank Hollow and Paint Cliff sites the slopes were graded to a smooth uniform configuration. After placement of the fill at Roberts Hollow two feet of soil cover was placed over the refuse. Agricultural limestone was added to the sites and tracked in with a bulldozer. The sites were fertilized, seeded, mulched, and netted. The sites were revegetated with a mix of warm and cool season grasses, legumes, and trees compatible with the surrounding vegetation (Figs. 12, 13)

Figure 10. Water Tank Hollow Refuse Area before reclamation.

Figure 11. Roberts Hollow Refuse Fill Area before reclamation.

Figure 12. Water Tank Hollow Refuse Area after reclamation.

Figure 13. Roberts Hollow Refuse Fill Area after reclamation.

Open Limestone Channels

Open limestone channels were installed at Cabin Branch, Co-op North portal, Roberts Hollow, Paint Cliff, Poplar Spring, and Water Tank Hollow. At the Co-op North portal and an unnamed tributary in Roberts Hollow OLCs were the only treatment technique used. Before and after installation data is available for these two sites enabling an assessment of the efficacy of this treatment technique at these sites.

At the Co-op North portal site pH ranged from 2.8 to 6.1 before installation of the 500 foot long OLC and ranged from 6.7 to 7.6 after construction of the OLC (Fig. 14). Acidity levels decreased and alkalinity increased (Fig. 15). The monthly average acid load prior to construction of the OLC was 1.2 metric tons (1.3 US tons) and the monthly average acid load post construction was zero (Fig. 16). Computer modeling of the proposed 500 foot OLC at the Co-op North portal indicated that the monthly acid load reduction would range from 12% to 91%. The actual acid load reduction to date is 100%.

The unnamed tributary in Roberts Hollow has a drainage area of 0.11 square miles. The tributary receives drainage from a coal processing refuse fill and deep mine portals located in Roberts Hollow. Flow in the tributary is intermittent with no flow during dry months. An open limestone channel (OLC) 800 feet in length was installed in the natural drain. Water monitoring was conducted near the mouth of the tributary before and after construction of the OLC.

The pH values ranged from 2.7 to 4.9 for the 13 sampling dates that had flow prior to construction of the OLC. The pH values ranged from 4.9 to 7.9 for the 13 sampling dates having flow after installation of the OLC (Fig.17).

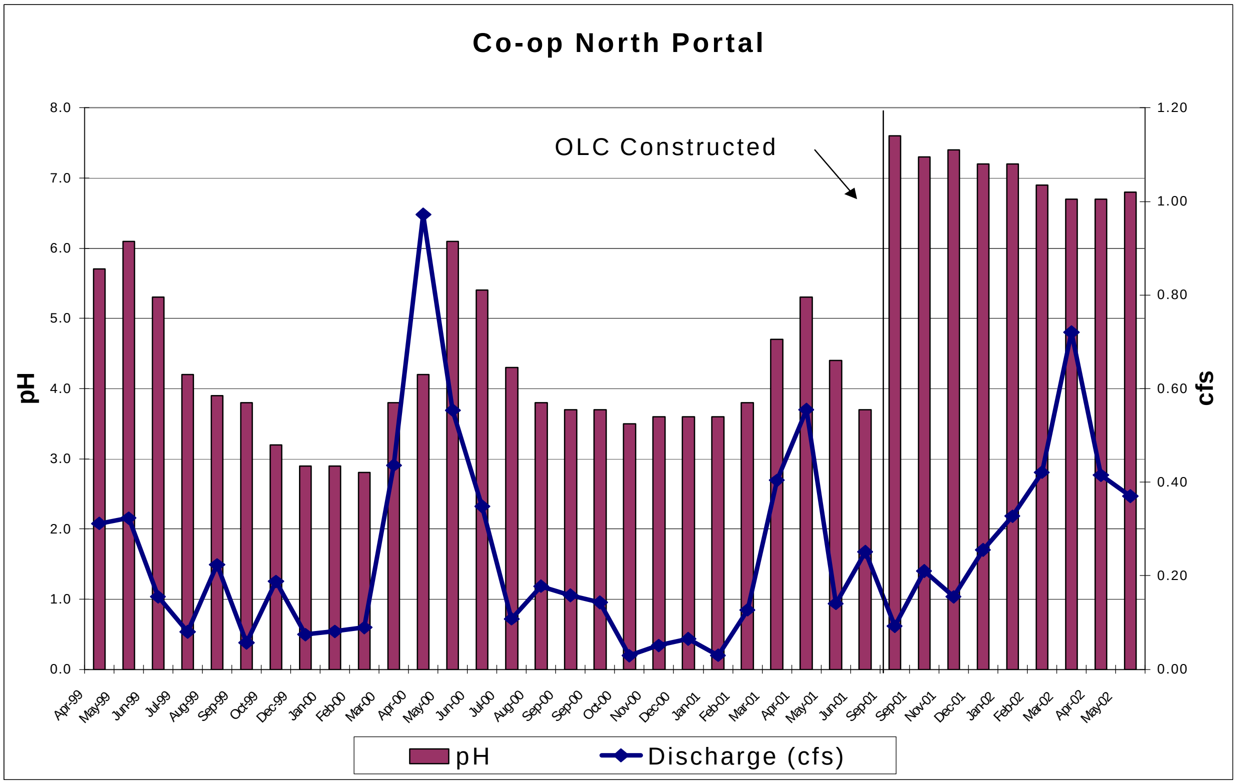

Figure 14. Co-op North drainage pH and discharge.

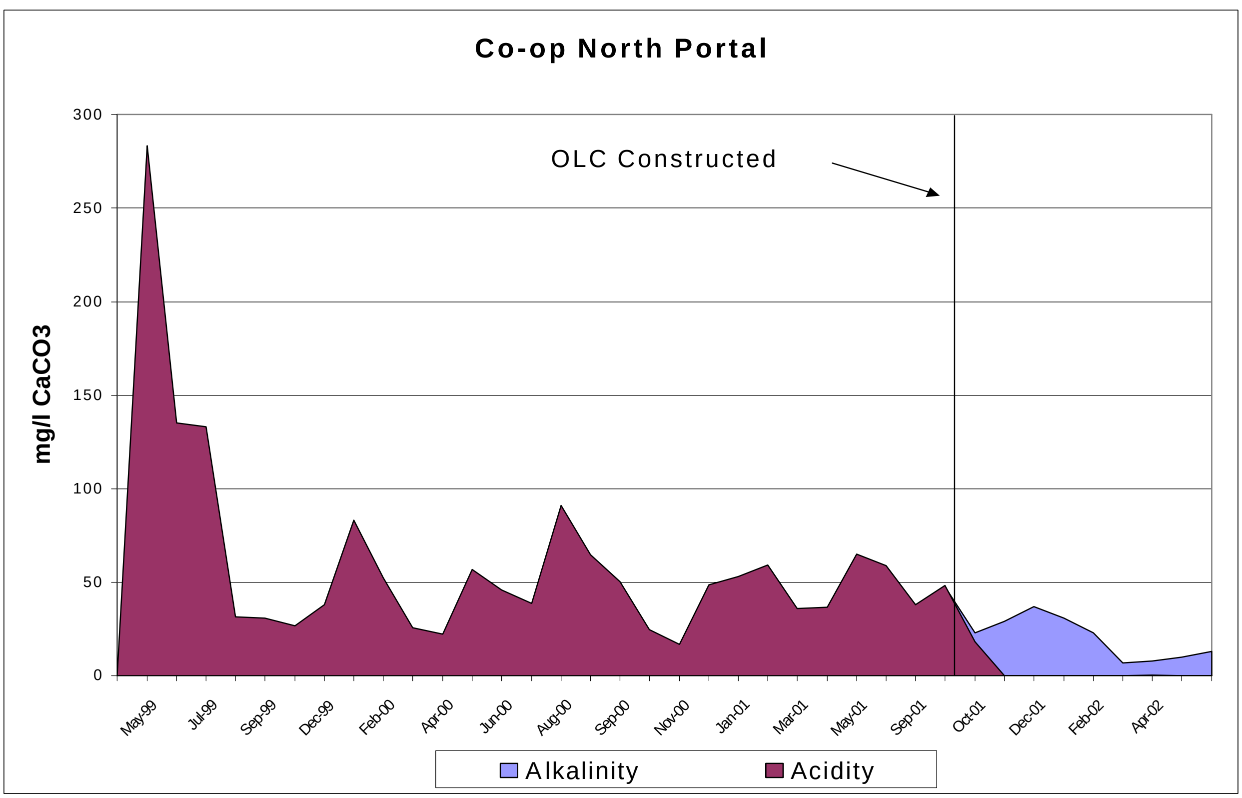

Figure 15. Co-op North drainage acidity and alkalinity.

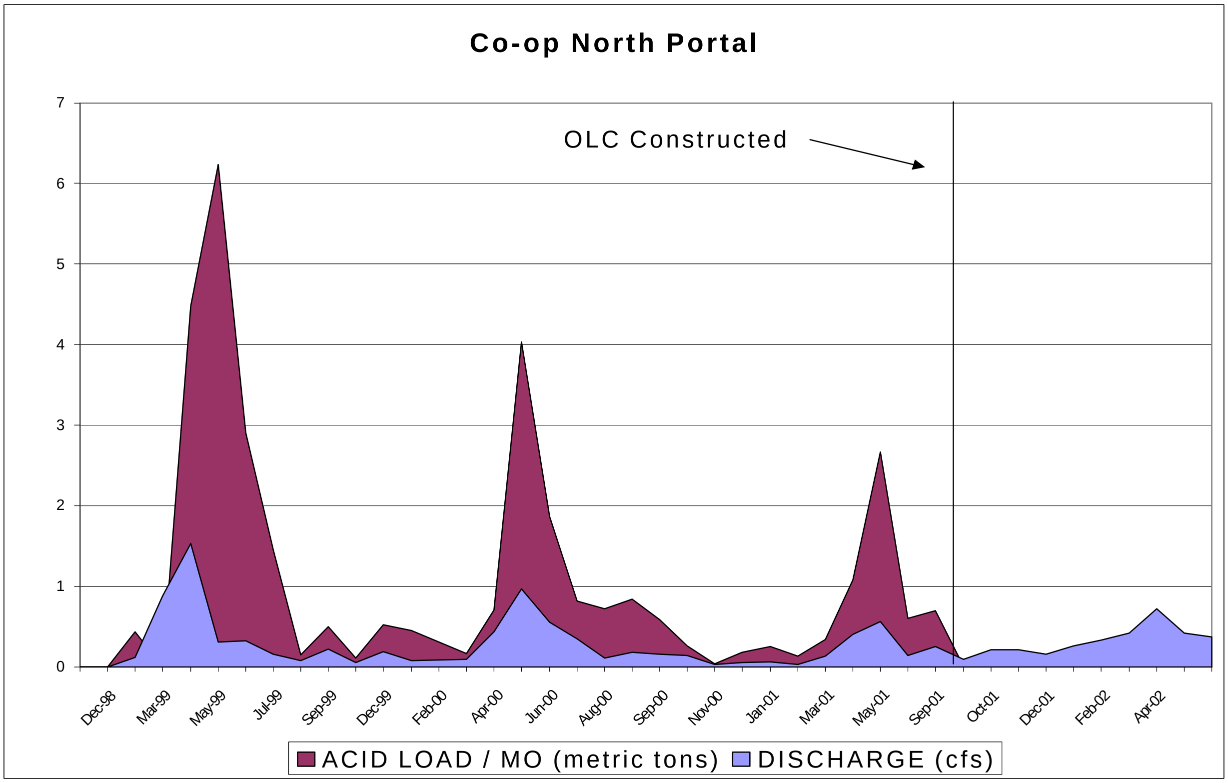

Figure 16. Co-op North discharge acid load.

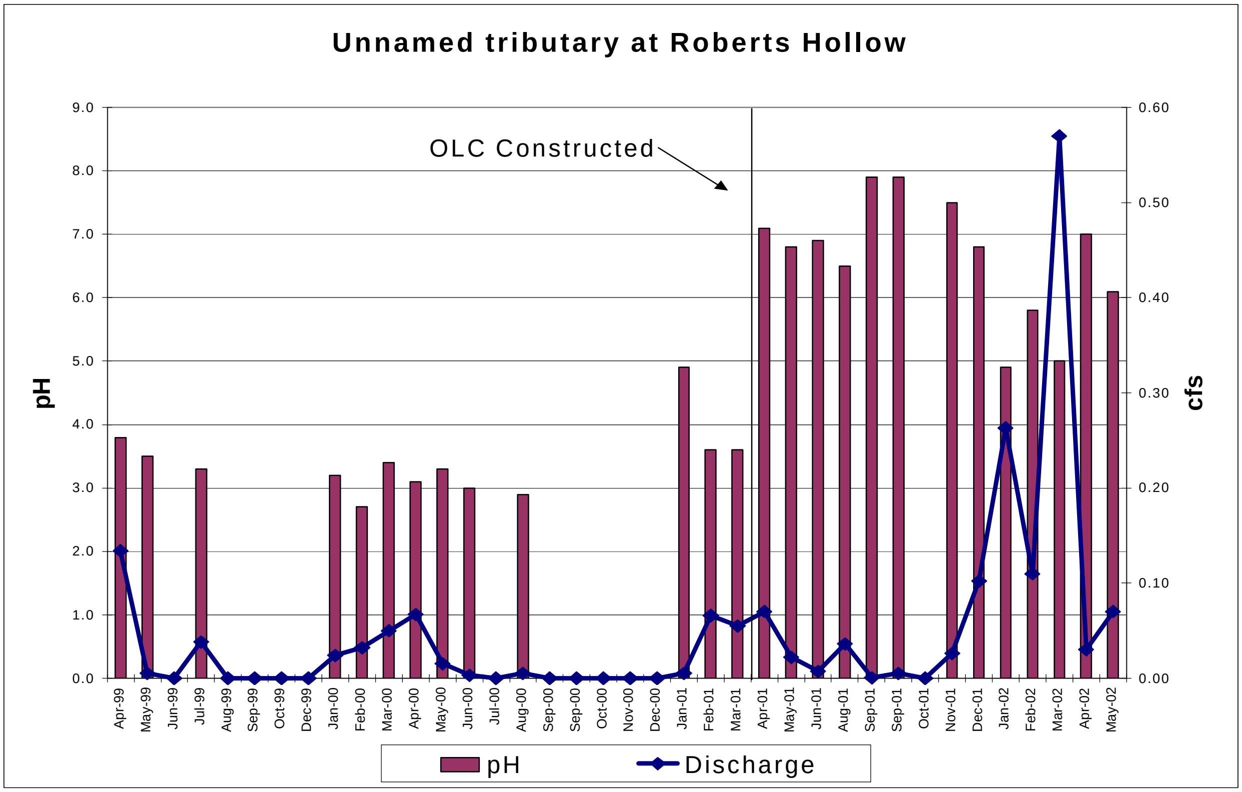

Figure 17. Unnamed tributary at Roberts Hollow pH and discharge.

Acidity decreased from an average of 182 mg/l CaCO3 pre-construction to an average of 38 mg/l CaCO3 after installation of the OLC. Alkalinity increased from 0 to an average of 54 mg/l CaCO3 after installation of the OLC. Net acidity was reduced 99% from an average of 182 mg/l CaCO3 to an average of 2 mg/l CaCO3 post construction. The tributary was net acidic until installation of the OLC when it became net alkaline for 10 of the 13 sampling periods post construction (Fig. 18). Net acid loading was near zero post construction (Fig. 19).

Vertical Flow System

A modified vertical flow system was constructed at the Paint Cliff site. The system receives AMD from a pyrite rich refuse fill and a deep mine discharge. The system has a direct connection between the treatment cell and a second cell via a 36-inch smooth wall pipe installed at the bottom of the treatment cell. The water elevation in the second cell controls the water elevation in the treatment cell. This setup eliminates the standpipe normally used for water elevation control. After a few months of use the spillway on the cell controlling the water elevation in the treatment cell had to be lowered to prevent flow from exiting the emergency spillway of the treatment cell. As precipitates accumulated in the treatment cell more head was required to drive the water through the system. After lowering the spillway of the second cell the water elevation of the treatment cell was about a foot higher than the adjusted water elevation in the second cell. This adjustment eliminated flow out of the emergency spillway in the treatment cell except during high flow events in late winter and early spring. The system is undersized to handle the entire flow during high flow events. An increase of freeboard in the treatment cell may allow it to handle larger flows with the increase in head.

An open limestone channel 100 feet in length intercepts the AMD before discharging into the sediment basin. Flow proceeds from the sediment basin into the treatment cell. Water is discharged from the vertical flow system into an OLC 100 feet in length. The water then flows through 500 feet of low gradient limestone lined ditch before discharging into Rock Creek. The last 500 feet of ditch was installed along the highway and does not function as treatment due to clogging with precipitates. The water quality data is for the entire treatment system and not just the vertical flow treatment cell.

The pH values ranged from 2.4 to 3.9 for the 16 sampling dates that had flow prior to construction of the vertical flow system. The pH values ranged from 4.8 to 6.2 for the 17 sampling dates after installation of the vertical flow system (Fig.20).

Acidity decreased from an average of 677 mg/l CaCO3 to an average of 25 mg/l CaCO3 after installation of the vertical flow system. Alkalinity increased from 0 to an average of 8 mg/l CaCO3 after installation of the OLC. Net acidity was reduced 96% from an average of 677 mg/l CaCO3 to an average of 26 mg/l CaCO3 post construction. The discharge was net acidic until installation of the vertical flow system when it became net alkaline for 10 of the 17 sampling periods post construction (Fig. 21). Net acid loading was near zero post construction with the exception of the September 25, 2001 sampling date when flow increased after a low flow period (Fig. 22).

This design has been in place for over a year and a half and has reduced acidity levels by more than 96% with no clogging problems to date. If the design proves to be successful over a long period of time it may be suitable for installation in high acid, high metal load conditions as found in the lower Rock Creek watershed.

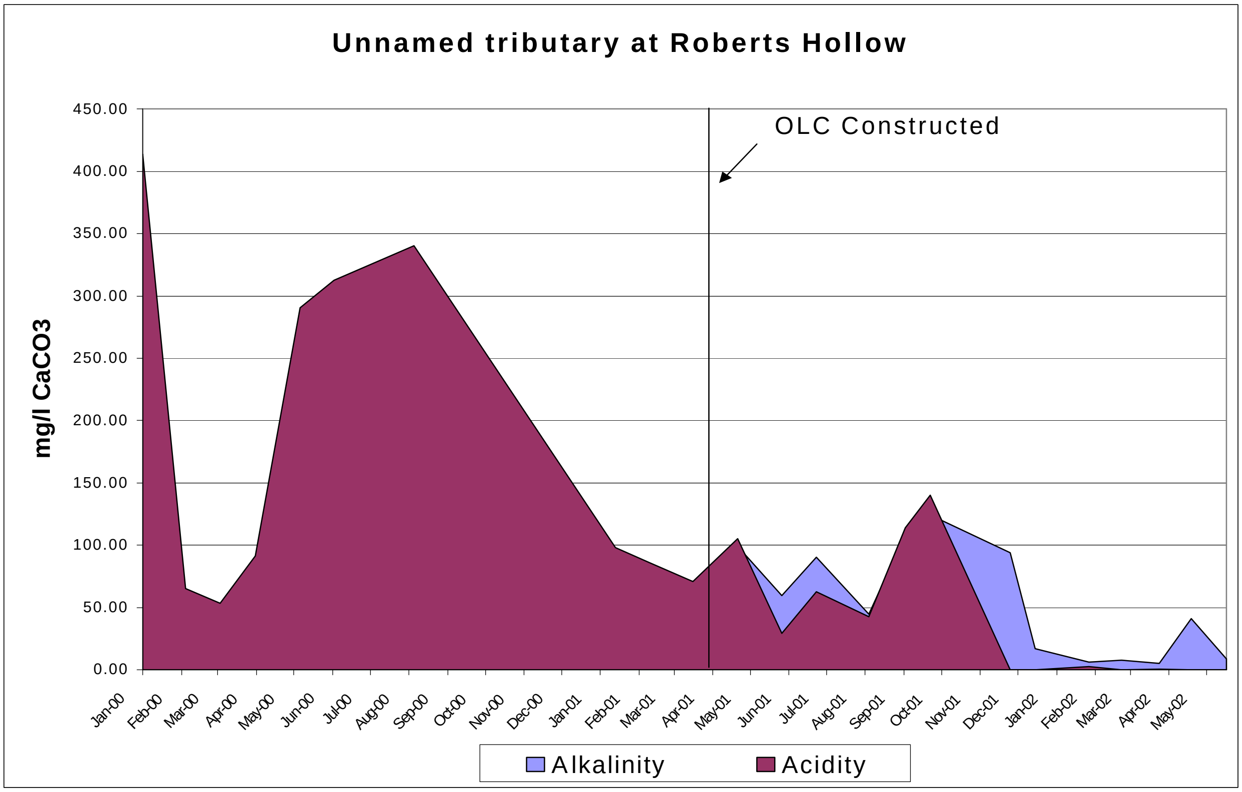

Figure 18. Unnamed tributary at Roberts Hollow acidity and alkalinity.

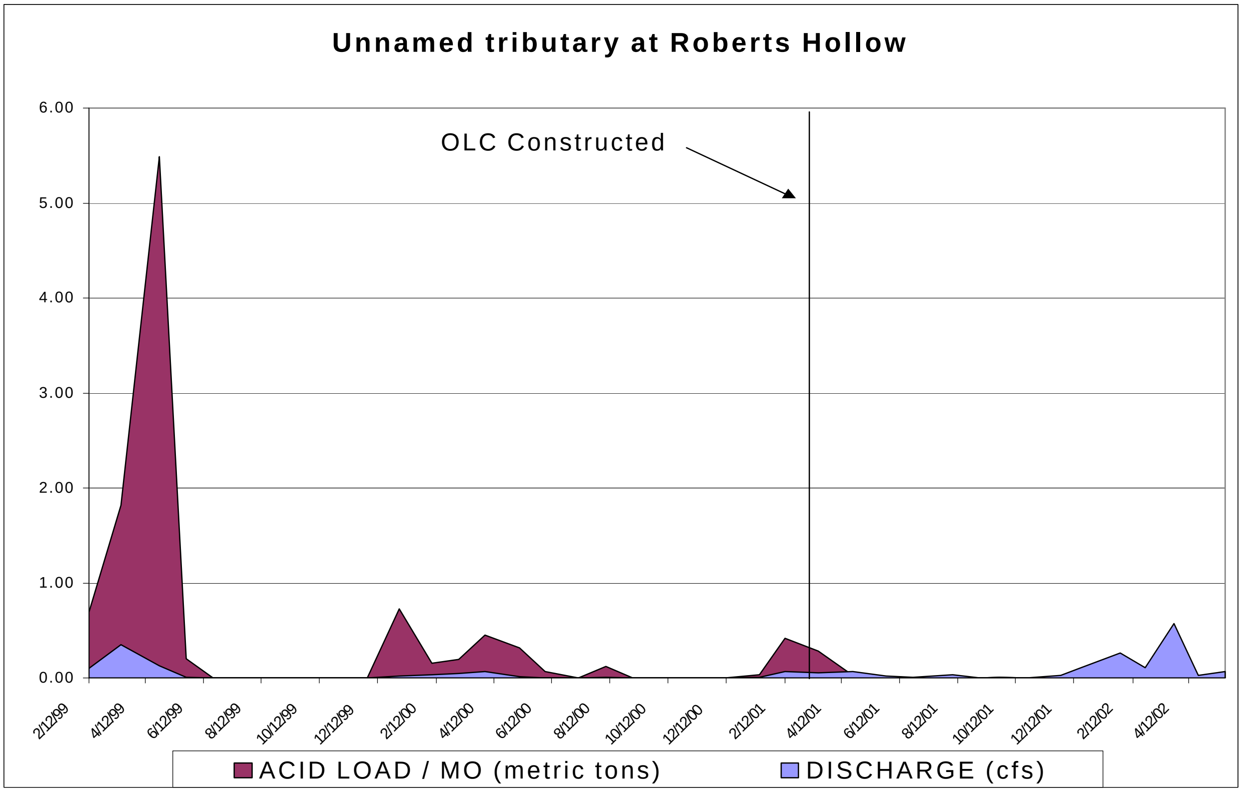

Figure 19. Unnamed tributary at Roberts Hollow acid load.

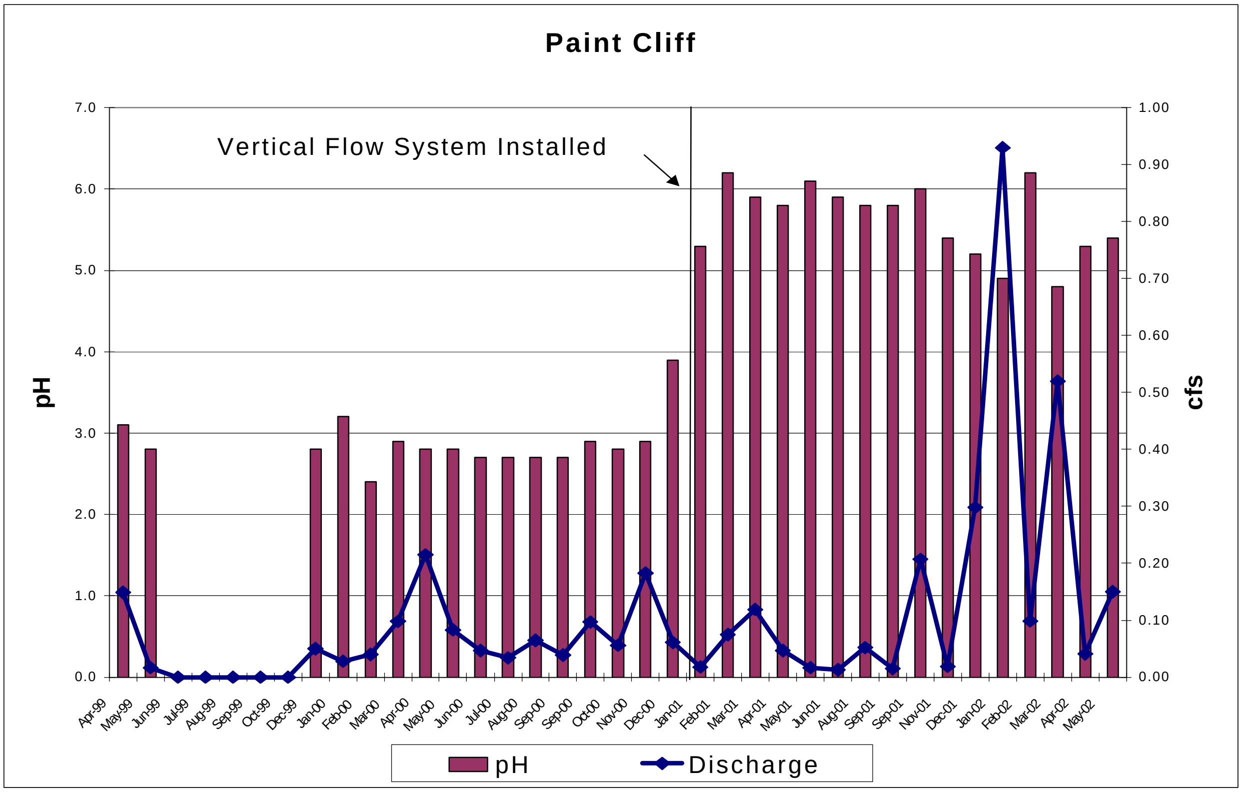

Figure 20. Paint Cliff pH and discharge.

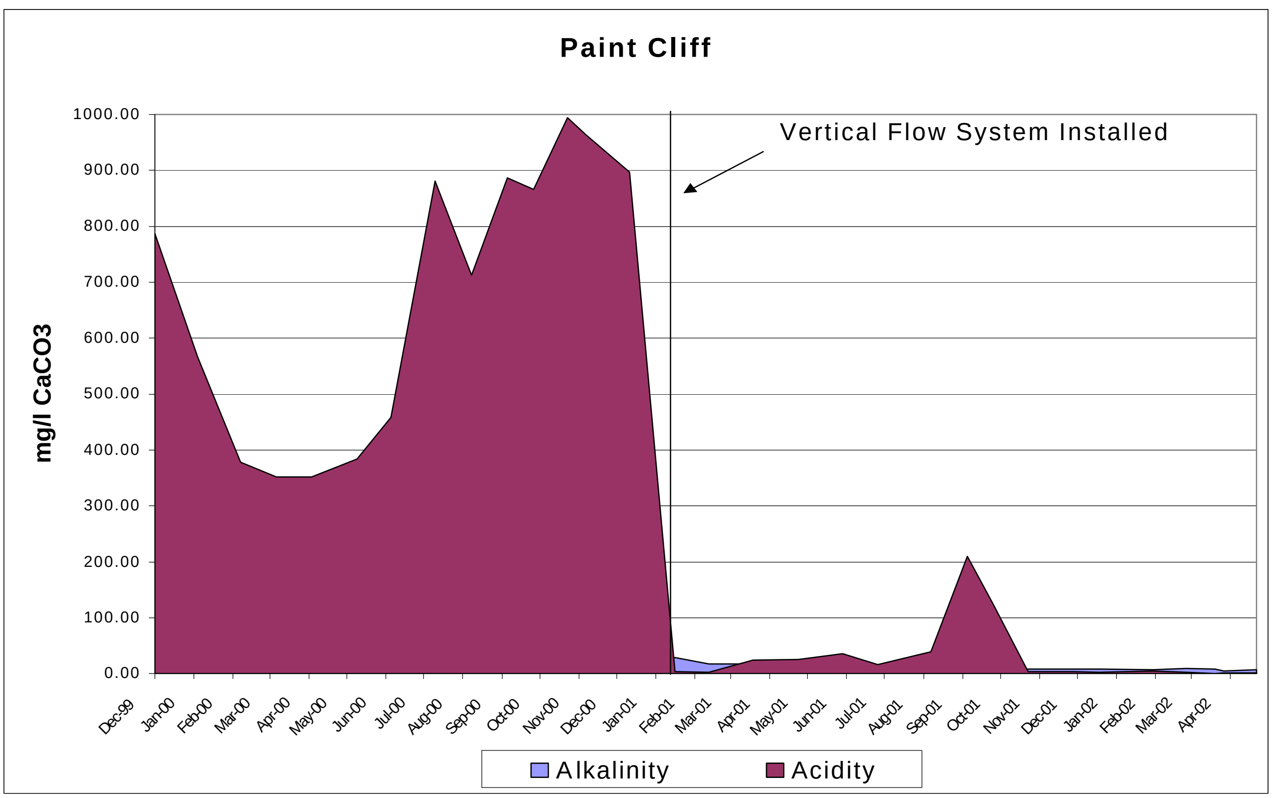

Figure 21. Paint Cliff acidity and alkalinity.

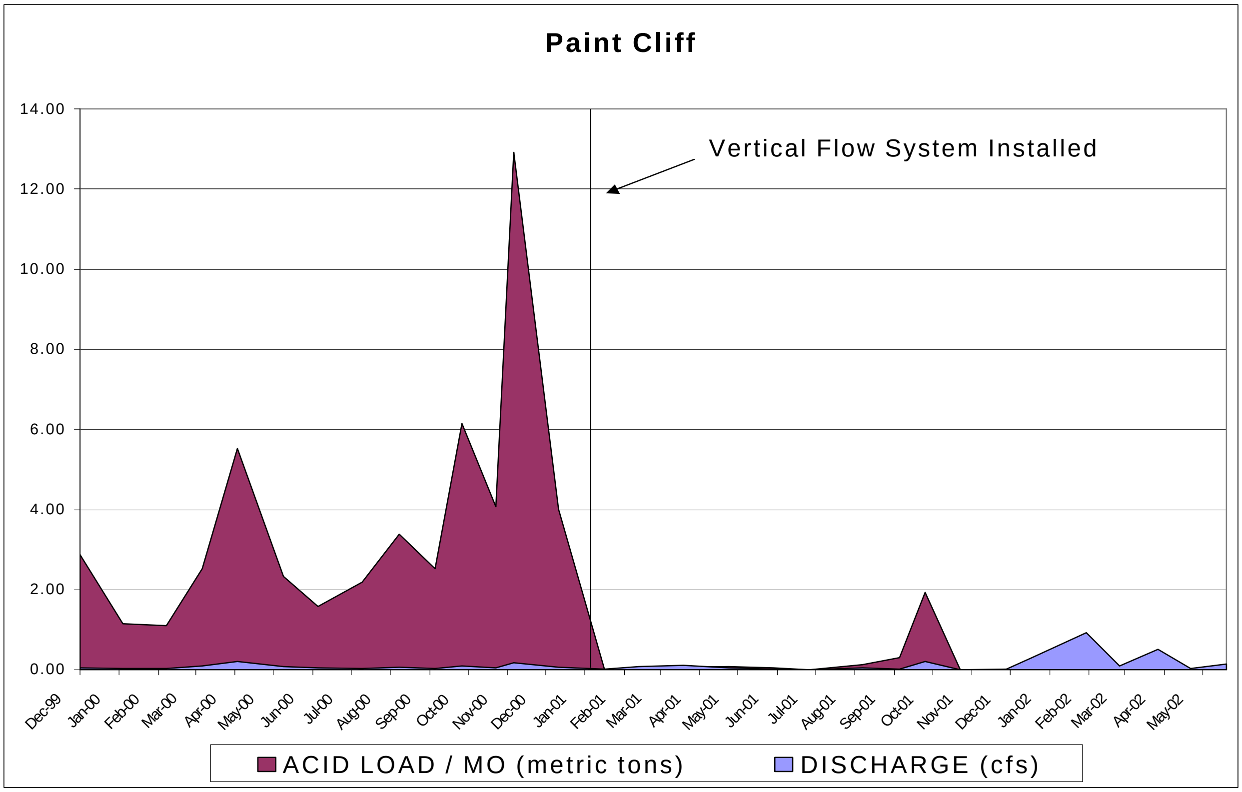

Figure 22. Paint Cliff acid load.

Biological Monitoring

Aquatic macroinvertebrates were collected spring/summer and fall/winter beginning in 1999. USFS personnel are analyzing aquatic macroinvertebrate results. Complete results of the macroinvertebrate study are not available at this time. Preliminary observations and results indicate that species diversity and numbers are improving. The proportion of intolerant orders appears to be increasing.

Fish were collected in early summer beginning in 1999. Monitoring station WO-01 is located upstream of the AMD impacted tributaries on White Oak Creek. Fish were sampled at this location on June 2, 1999. Only three species were collected. Blackside dace, a federally threatened species, was one of the three species collected. Blackside dace were previously unknown in this watershed. The total IBI on this sampling date was 32, a ranking of poor. Due to the presence of Blackside dace in this stream segment and this monitoring station's role as an upstream control the decision was made to suspend sampling at this site.

Monitoring station WO-02 is located immediately downstream from the mouth of Cabin Branch; the first AMD impacted tributary discharging into White Oak Creek. This site was sampled twice in 1999. On both of the sampling dates, June 2, 1999 and October 19, 1999, no fish were collected from this stream segment. In February 2000 dosing of the stream with sand-sized limestone particles began. On July 17, 2000, six months after limestone dosing began, one species of fish was collected from this previously dead section of stream. Ninety-one creek chubs, a tolerant species, were collected. The total IBI for this stream segment on this date was 26, a ranking of very poor to poor. On July 23, 2001 this stream segment was sampled again. Four species of fish were collected on this previously dead section of stream including barcheek darters and the federally endangered blackside dace, both intolerant species. The total IBI was 34 a ranking of poor (Fig. 23).

Monitoring station RC-00 is located immediately upstream from the mouth of White Oak Creek on Rock Creek and is the upstream control site for Rock Creek. This site was sampled only once, August 5, 1999, due to its role as an upstream control site. There were 10 species of fish collected, six of which were intolerant species. The total IBI was 40, a ranking of fair.

Monitoring station RC-01 is located on Rock Creek immediately downstream from the confluence with White Oak Creek. The water quality in this section of stream is highly variable. During periods of low flow the entire flow of Rock Creek immediately upstream is diverted through a cave, discharging from a spring 3000 feet downstream from the monitoring site. This results in the water at this site during low flow being entirely from the White Oak Creek watershed. In addition, a spring discharges at this site whose source is the severely AMD impacted Jones Branch tributary. During high flow this section of stream receives water from the high water quality section of Rock Creek. The highly variable nature of the water quality and the mobility of fish result in dramatic changes in fish populations on different sampling dates. This site was sampled on three separate dates in 1999. On June 2, 1999 nine species of fish were collected, five of which were intolerant species. The IBI was 44, a ranking of fair. Two months later on August 5, 1999 only three species of fish were collected, one of which was an intolerant species. The IBI on this date was 24, a ranking of very poor. Two months after the August sampling date on October 19, 1999 the stream segment was sampled again. Sixteen species of fish were collected; seven of which were intolerant species. The IBI on this date was 40, a ranking of fair. On July 17, 2000 the stream segment was again sampled. Limestone dosing began six months prior to this sampling date. The total number of species collected was six, three of which were intolerant species. The IBI on this date was 32, a ranking of poor. On July 23, 2001 the stream segment was sampled again. Eight species of fish were collected; four of which were intolerant species. The IBI on this date was 32, a ranking of poor (Fig. 24).

Monitoring station RC-02 is located on Rock Creek immediately downstream from the mouth of Roberts Hollow. This stream segment was sampled three times in 1999. On June 2, 1999 no fish were found. On August 5, 1999 five species were collected, three of which were intolerant species. The IBI was 34, a ranking of poor. On October 19, 1999 this stream segment was sampled and again no fish were collected. On July 17, 2000, six months after limestone dosing began, 13 species, nine of which were intolerant species, were collected. The IBI on this date was 44, a ranking of fair. On July 23, 2001 sampling resulted in the collection of nine species, seven of which were intolerant species. On this date a brown trout was collected, the first trout to be collected on the AMD impacted section of Rock Creek. The IBI on this date was 42, a ranking of fair (Fig. 25).

Monitoring station RC-O3 is located on Rock Creek at the mouth of Koger Fork. This site was sampled three times in 1999. On June 2, 1999 13 species of fish were collected, eight of which were intolerant species. The IBI for this date was 46, a ranking of fair to good. On August 26, 1999 only two species of fish were collected, one of which was an intolerant species. The IBI for this date was 29, a ranking of poor. On October 19, 1999 12 species of fish were collected, eight of which were intolerant species. The IBI for this date was 48, a ranking of good. On July 17, 2000, six months after limestone dosing began, the number of species collected was 13, eight of which were intolerant species. The IBI was 37, ranking poor to fair on this date. The presence of green sunfish and the increase in largescale stonerollers lowered the

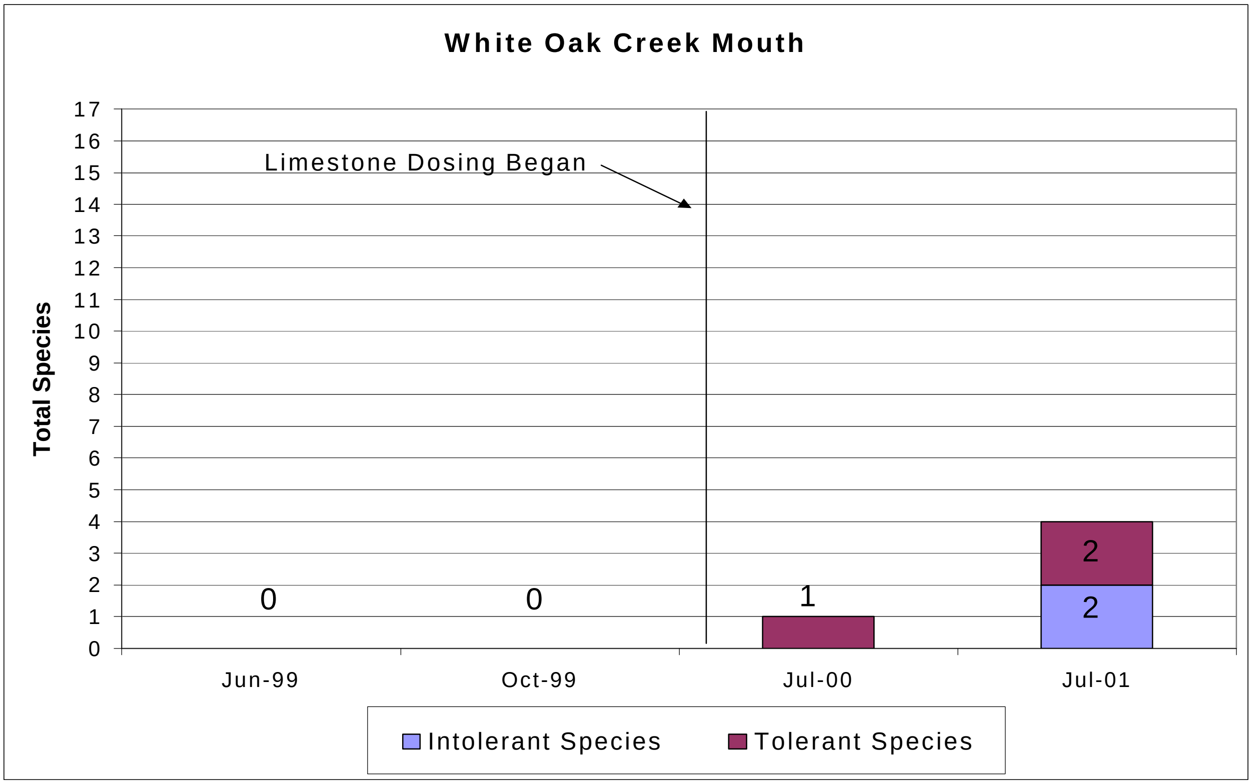

Figure 23. White Oak Creek station WO-02 fish species.

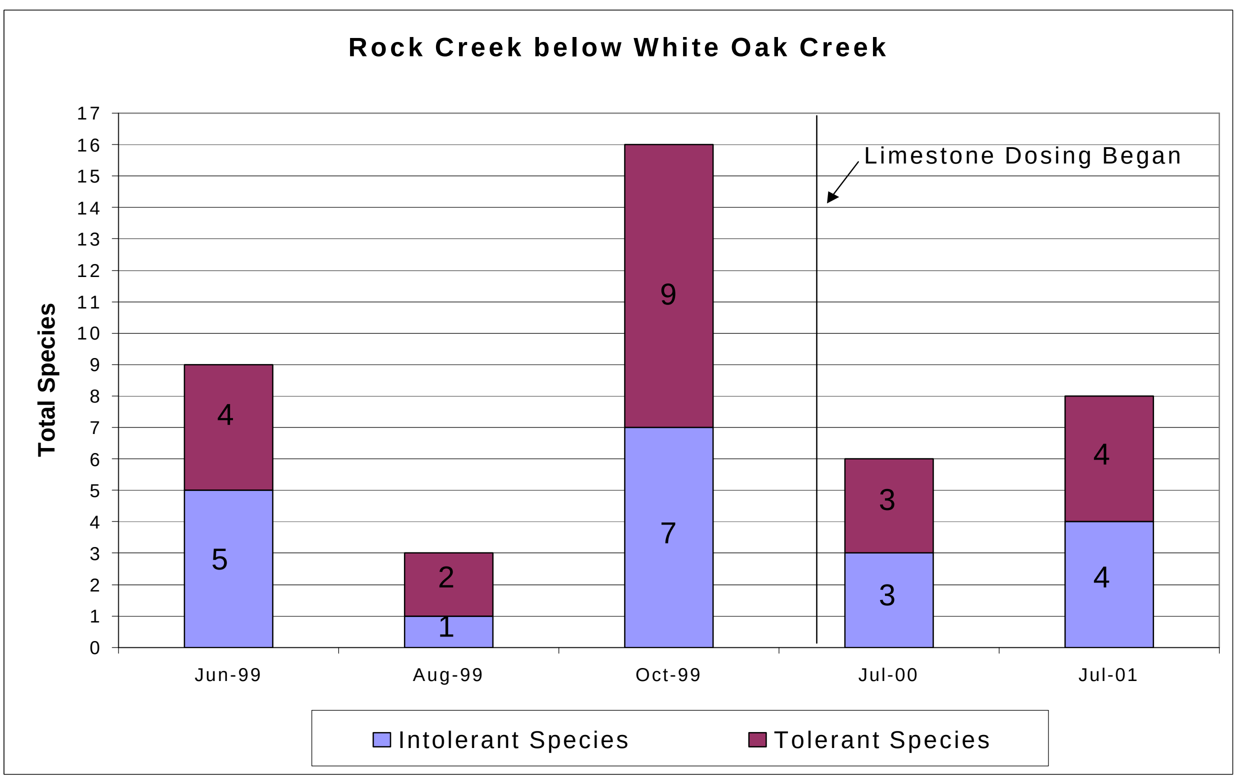

Figure 24. Rock Creek station RC-01 fish species.

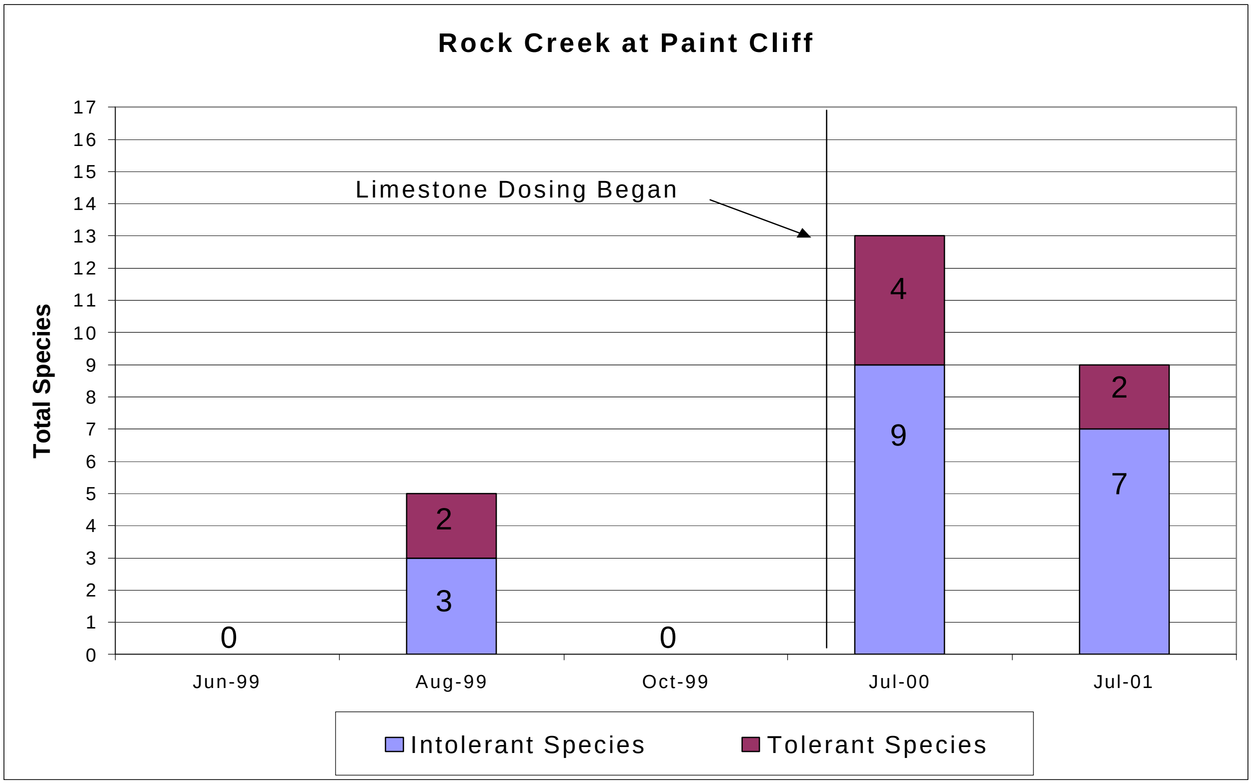

Figure 25. Rock Creek station RC-02 fish species.

IBI score. On July 23, 2001 the number of species collected increased to 15, with 11 species being classified as intolerant. The IBI on this date was 48, a ranking of good (Fig. 26).

Monitoring station RC-04 is located on Rock Creek at the mouth of Grassy Fork, immediately downstream from the Water Tank Hollow site. This stream segment was sampled three times in 1999. On June 2, 1999 10 species were collected, five of which were intolerant species. The IBI on this date was 38, a ranking of poor to fair. On August 26, 1999 six species of fish were collected, with three species being classified as intolerant species. The IBI on this date was 34, a ranking of poor. On October 19, 1999 only two species were collected, none of which are classified as intolerant. The IBI for this date was 22, a ranking of very poor. On July 17, 2000, six months after limestone dosing began, 14 species were collected; seven of which are classified as intolerant. The IBI for this date was 44, a ranking of fair. On July 23, 2001 10 species were collected, with eight species classified as intolerant. The IBI on this date was 46, a ranking of fair to good (Fig. 27).

Fish populations have increased in both diversity and numbers in the White Oak Creek and lower Rock Creek watersheds since limestone dosing and AMD abatement reclamation in the watersheds began. Stream segments in both White Oak Creek and Rock Creek that were dead or severely stressed have improved. IBI scores have consistently increased after limestone dosing and AMD abatement reclamation practices were initiated. Additional AMD abatement reclamation projects in the lower Rock Creek watershed will further improve water quality in the watershed, positively impacting fish populations.

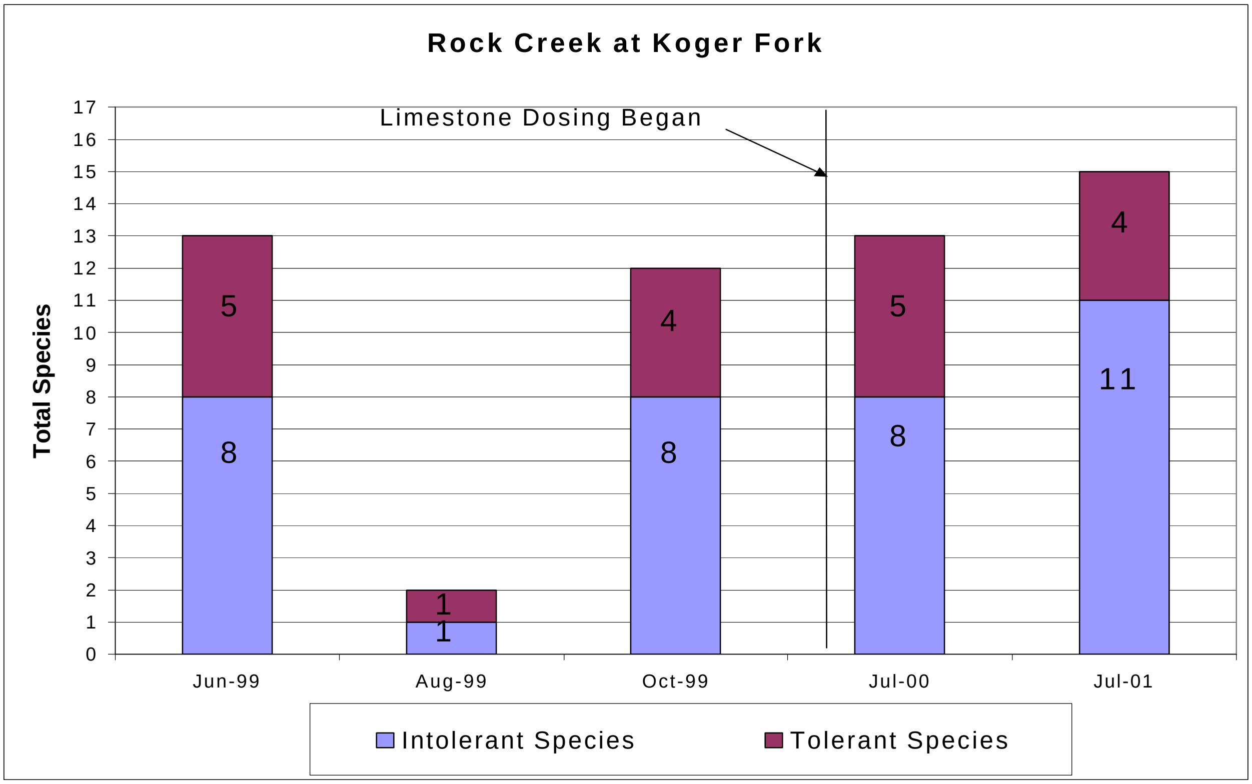

Figure 26. Rock Creek station RC-03 fish species.

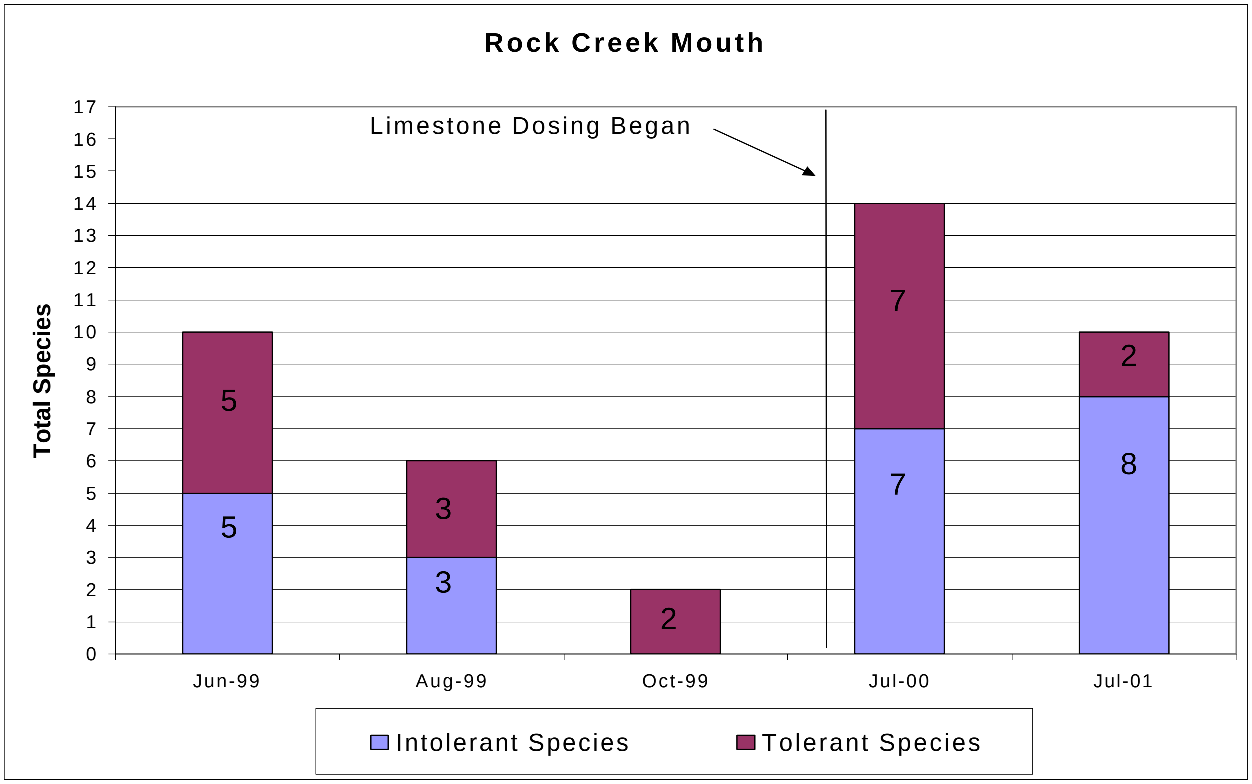

Figure 27. Rock Creek station RC-04 fish species.

CONCLUSIONS

Acid loading from Rock Creek into the Big South Fork of the Cumberland River has been reduced from a monthly average of 110 metric tons (121 US tons) to near zero after completion of the Rock Creek Acid Mine Drainage Abatement Project. Techniques used to accomplish this goal include monthly dosing with limestone sand, removal and treatment of acidic refuse from the banks of Rock Creek, installation of open limestone channels, and installation of a modified vertical flow system at Paint Cliff.

Monthly dosing of selected tributaries in the lower Rock Creek watershed has resulted in a change from net acidity to net alkalinity at Rock Creek's confluence with the Big South Fork of the Cumberland River. Monthly dosing has also resulted in a change from net acidity to net alkalinity in White Oak Creek at its confluence with Rock Creek. The use of the direct application of limestone sand to the tributaries has resulted in significant reductions in acidity at very low cost. This method can be used to improve water quality in impacted streams while sources of funding for more permanent abatement techniques is being sought. As funding levels increase and reclamation is performed, limestone dosing may be reduced or eliminated.

Removal of 25,000 cubic yards of pyritic coal mine refuse from the north bank of Rock Creek at the three acre Water Tank Hollow site and the Paint Cliff site has eliminated over 80 tons of acidity entering Rock Creek annually from direct washing of the refuse into the stream. Revegetation of the sparsely vegetated site has reduced the sediment load into Rock Creek by 500 tons annually. Treating the pyritic coal mine refuse from the Water Tank Hollow site and the Paint Cliff site by mixing it with agricultural limestone and placing it in compacted lifts at the pre-existing Roberts Hollow refuse fill reclaimed two acres of sparsely vegetated refuse. The combination of the treated refuse and the installation of OLCs reduced acid groundwater seepage entering the Roberts Hollow tributary. Revegetation of the site further reduced the sediment load entering the stream at Roberts Hollow.

Installation of the open limestone channels (OLCs) at the Co-op North portal drainage and at the unnamed tributary below Roberts Hollow has reduced net acidity by 100% and 99% respectively. Acid loading has been reduced to zero at the Co-op North site and to near zero at the unnamed tributary site. Installation of the OLCs has resulted in an increase in pH, calcium concentrations, and alkalinity, and a corresponding decrease in acidity and dissolved metals. The documented changes in water chemistry illustrate the value of OLCs in treating acid mine drainage.

Installation of the modified vertical flow system at Paint Cliff has greatly improved water quality at a high acidity, high metal load discharge site. The sites close proximity to Rock Creek limited the room for alternative abatement techniques. The high aluminum concentration in the water gave concern for the installation of a conventional vertical flow system with smaller diameter drainage pipes and a standpipe. The flow-through design installed at Paint Cliff may minimize plugging of the limestone bed with precipitates. To date there has been no problem with plugging, however the outlet spillway elevation had to be lowered to adjust the water elevation in the treatment cell after initial coating of the limestone layer above the organic layer with precipitates. The spillway has only needed to be adjusted once. The system as designed can not handle the entire flow during high flow events. Diversion of the excess flow into a second vertical flow system would solve this problem. An increase in freeboard on the treatment cell may also solve the problem by adding storage and increased head as the water level rises. The treatment system is currently reducing acidity levels by an average of 650 mg/l $CaCO_3$.

Previous studies have found that 300 mg/l CaCO3 reductions in acidity is the upper limit for this type of system. The acid reduction seen at this site may not be sustainable in the long term. If the modified design proves to be successful over a longer period of time a second treatment system may be installed in series with the first.

The combination of the reclamation techniques used on the above sites in conjunction with limestone sand dosing in the lower Rock Creek watershed has reduced the acid load entering the Big South Fork of the Cumberland River to near zero. Fish populations are rebounding with increases in numbers, diversity of species, and numbers of intolerant species. Sections of the streams that were once dead or severely impacted by AMD are being re-colonized by fish.

Additional reclamation work being planned for the severely impacted tributaries of Jones Branch, Roberts Hollow, and Poplar Spring Hollow will continue to reduce acid and metal loading, improving water quality further in the lower Rock Creek watershed. As additional funding allows reclamation projects in other impacted tributaries in the lower Rock Creek watershed the dependence on limestone dosing of the tributaries will be reduced.

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